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Notes

Introduction to the development, evolution and petroleum geology of the Wessex Basin

JOHN R. UNDERHILL¹ & ROBERT STONELEY²

¹*Department of Geology & Geophysics, The University of Edinburgh, Grant Institute, Kings Buildings, West Mains Road, Edinburgh EH9 3JW, UK
(e-mail: jru@glg.ed.ac.uk)*

²*1A Pelham Court, 145 Fulham Road, London SW3 6SH, UK*

Abstract: Despite containing the largest known onshore oilfield in western Europe, the Wessex Basin hydrocarbon province appears to be extremely limited spatially and it currently only consists of three producing oilfields: Wytch Farm, Wareham and Kimmeridge. The main factor which controls hydrocarbon prospectivity in the area appears to be preservation of oil accumulations originally sited in Mesozoic tilted fault-blocks. The extensional palaeostructures of Wytch Farm and Wareham are interpreted to have been charged by upwards migration of oil from mature Liassic source rocks situated across the Purbeck–Isle of Wight fault system in the Channel (Portland–Wight) sub-basin prior to, and unaffected by, either significant effects of intra-Cretaceous (Albian–Aptian) easterly tilting or by Tertiary tectonic inversion. To date, only the small Kimmeridge oilfield, which is situated in the core of a periclinal fold created in response to structural inversion, suggests that any hydrocarbon remigration into younger structural inversion structures has taken place.

Basin definition

The Wessex Basin as defined here consists of a system of post-Variscan sedimentary depocentres and intra-basinal highs that developed across central southern England and adjacent offshore areas (Figs 1 & 2). Given its limits in age and area, the Wessex Basin may be considered to represent a series of extensional sub-basins that form a component part of a more extensive network of Mesozoic intracratonic basins that covered much of NW Europe (Ziegler 1990). Like many of the other basins around the British Isles (e.g. the Weald Basin, Southern North Sea, Cleveland Basin etc.), the Wessex Basin also records the effects of Cenozoic intra-plate contraction and structural inversion of basin-bounding and intra-basinal faults.

Onshore the geological boundaries to the Wessex Basin are such that it covers a similar area to the ancient kingdom of the West Saxons and includes the present counties of Hampshire and Dorset, together with parts of East Devon, Somerset and Wiltshire. The basin is bound to the southwest and west by the Armorican and Cornubian Massifs, to the north by the London Platform (otherwise known as the London–Brabant massif) and to the south by the Central Channel High (Fig. 2). Its northeastern and northwestern boundaries are less precisely defined. Although the distinction between the Wessex Basin and the Weald Basin of Sussex, Surrey and Kent is usually taken to be marked

by a fundamental change in subsurface geology running NW along Southampton Water, the WNW–ESE trending Chalk (South Downs) outcrop is included in the descriptions herein

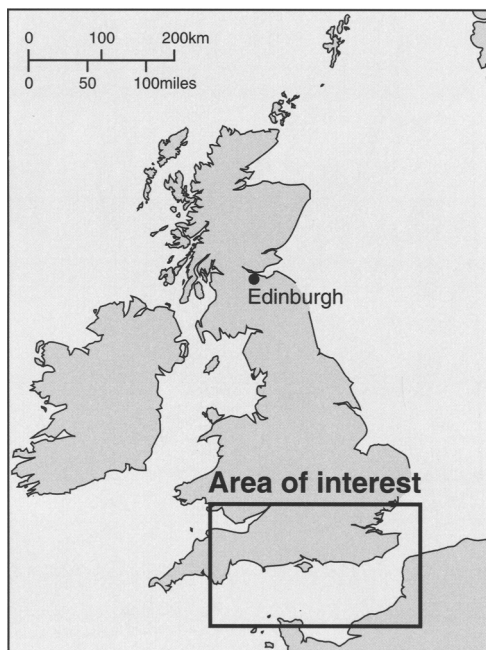


Fig. 1. Location map indicating the area covered by Fig. 2.

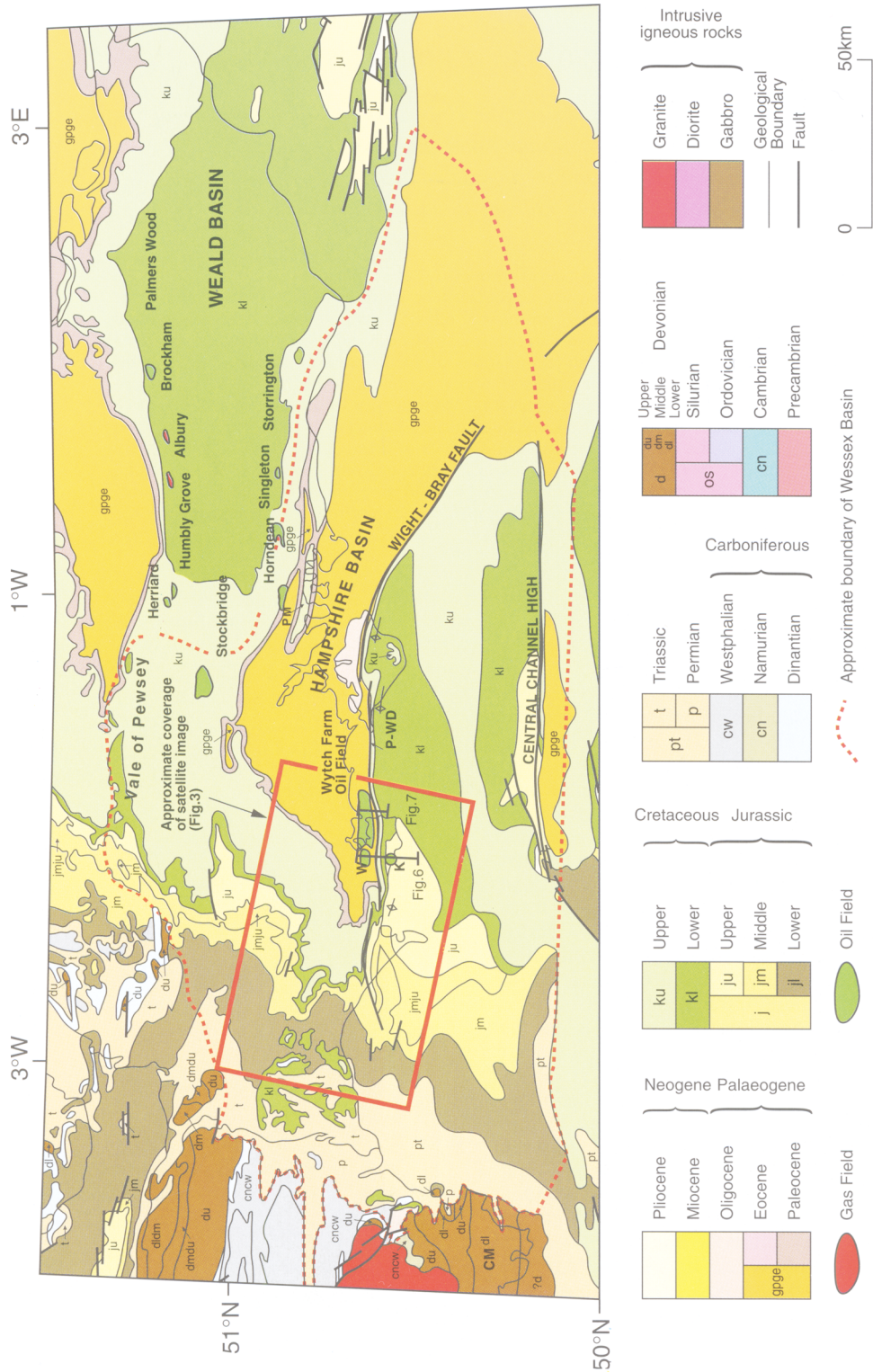


Fig. 2. Geological outcrop and subcrop patterns in southern England and the English Channel. The limits of the Wessex Basin as defined in this paper are indicated. W, Wareham oilfield; K, Kimmeridge oilfield. The position of the seismic and/or geological sections used in Figs 6 & 7 and the approximate limits of the satellite image used in Fig. 3 are shown.

so as to include the Portsdown Anticline in the basin (Fig. 2). Although areas to the northwest of the basin have affinities with the Wessex Basin (e.g. Bristol Channel Basin), its NW limit is taken to be marked by a poorly defined boundary running from the Quantock Hills across the Central Somerset Trough south of the Mendips to the western extension of the London Platform (Fig. 2).

Structural components

The Wessex Basin itself can be subdivided into a number of component parts, bounded primarily by several important exposed or buried tectonic elements, the most significant of which are given below.

The *Pewsey fault system* and *Central Channel High* which are taken to define the northern and southern margins of the Wessex Basin respectively.

The *Purbeck–Isle of Wight Disturbance* (Figs 2, 3 & 4) together with the underlying Mesozoic

Purbeck–Isle of Wight fault system, effectively separates the *Channel* (or *Portland–Wight*) *Basin* to the south from the *South Dorset Shelf* and *Hampshire–Dieppe* (or Cranborne–Fordingbridge) intrabasinal highs.

Other structural elements are also wholly intra-basinal. Two E–W-trending extensional faults define a narrow *South Dorset Basin* (otherwise known as the Winterborne Kingston Trough or Cerne Basin) within the *South Dorset Shelf*. The *Wardour* and *Portsdown* fault systems represent important sets of intra-basinal extensional growth faults prior to their reverse reactivation in the Tertiary. Finally, the largely subsurface NNW–SSE-trending *Watchet–Cothelstone–Hatch* fault system transects the basin (Miliorizos & Ruffell this volume).

During Tertiary times, the main site of deposition differed from those of the important Mesozoic basins. Following the latest Cretaceous–early Tertiary inversion, sedimentation was mainly restricted to the *Hampshire Basin* which lay above the site of the former Hampshire–Dieppe High (Plint 1982, 1983,



Fig. 3. Satellite image of the South Dorset area showing the significant topographic effect created by the steep limbs of northward facing monoclinical folds formed in response to Tertiary structural inversion. The approximate location of the satellite image is shown on Fig. 2. Produced with permission of Earth Images Ltd.

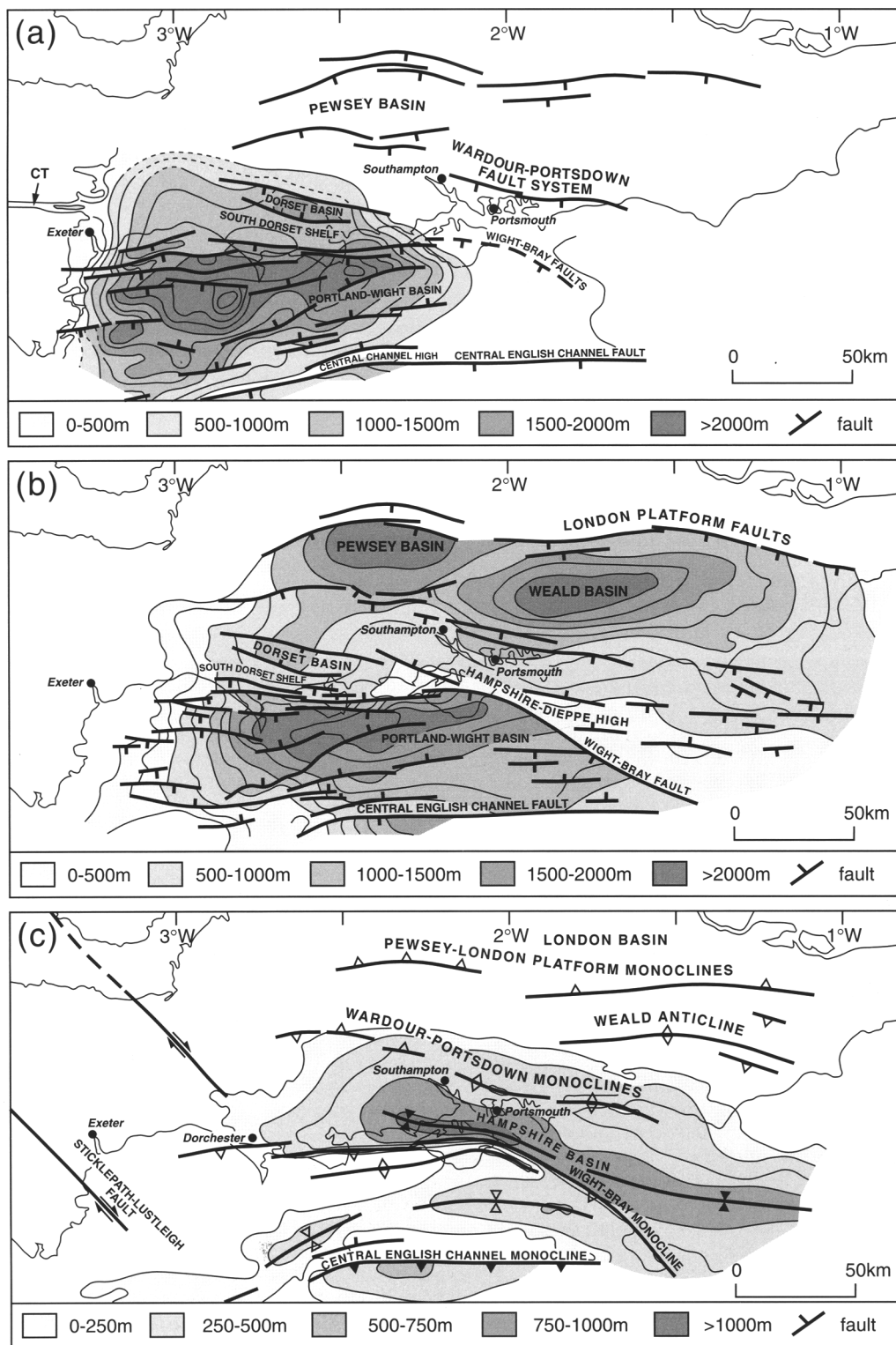


Fig. 4. Sedimentary depocentres and the main structural elements of southern England. (a) Permo-Triassic (CT, Credon Trough); (b) Jurassic-Cretaceous; (c) Cenozoic. (Modified after Hamblin *et al.* 1992.)

1988). Although temporally and spatially distinct from the main sites of Mesozoic basin development, the Hampshire Basin is still considered an integral part of the Wessex Basin since it records the syn- and post-contractual deformation and sedimentation history of the region.

Stratigraphic framework

The basic stratigraphy and structure of the Wessex Basin are well displayed in the coastal cliffs and inland districts of South Dorset, east Devon and the Isle of Wight. These outcrops, and deductions made from them, enable predictions to be made about the possible occurrence of oil and gas in the subsurface, which can then be tested by reference to information now available from exploratory wells and from seismic data (e.g. Stoneley, 1982; Chadwick 1986; Penn *et al.* 1987; Selley & Stoneley 1987).

Temporally, the sedimentary history of a distinctive Wessex Basin post-dates the development and closure of the Devonian-Carboniferous Proto-Tethys or Rheic Ocean (Glennie & Underhill 1998). The occurrence of major thrust faults, intense folding, regional metamorphism and intrusion of major granitic batholiths (such as the Dartmoor Granite) all attest to the severity of Variscan collisional processes. The deformed Devonian-Carboniferous sediments lie beneath a marked unconformity which represents the effective lower limit to reservoir potential in the Wessex Basin (Smith 1993).

Extensional basin development and its component sedimentary fill history began in the Permian within the Variscan fold-and-thrust belt hinterland and continued until the Late Cretaceous in the Wessex Basin (*sensu stricto*; Fig. 4a & b). The sedimentary fill of the successor Hampshire Basin is entirely Tertiary with the youngest sediments being of Oligocene age (Fig. 4c). Except for localized volcanics close to the base (Exeter Volcanic Series), the basin is wholly devoid of igneous rocks. In general terms, the Permian–Oligocene succession may be separated into three internally conformable but unconformity bound mega-sequences (e.g. Hawkes *et al.* this volume): the Permian to Lower Cretaceous, Upper Cretaceous and Tertiary megasequences.

Permian–Lower Cretaceous megasequence

The Permian to Lower Cretaceous interval has been the subject of intensive stratigraphic and

sedimentological studies. For example, Ainsworth *et al.* (this volume a & b) provide a detailed biostratigraphic calibration and lithostratigraphic subdivision of the megasequence and its component parts. Although some sequence stratigraphic studies of the Jurassic section have focused upon the recognition and correlation of sequence boundaries (e.g. Coe 1995, 1996; Hesselbo & Jenkyns 1995), more recent efforts have attempted to define maximum flooding surface-bound, genetic stratigraphic sequences or depositional episodes (*sensu* Galloway 1989; Underhill & Partington 1993, 1994). In particular, Cole & Harding (this volume) use palynofacies to define genetic stratigraphic sequences in the Lower Jurassic with a view to enabling comparison with those defined in the North Sea and adjacent areas (e.g. Partington *et al.* 1993).

The acquisition of significant subsurface data together with the recent advances in sequence stratigraphic methods support earlier interpretations that subdivided the Permian–Lower Cretaceous megasequence into three component parts (Fig. 5).

The lowest division consists of Permian and Triassic continental (red bed) sediments, in which all desert environments are represented. Deposition was initially restricted to intramontane basins such as the Crediton Trough that developed due to extensional collapse of the former Variscan mountain belt. Although there is much alternation, the sequence is characterised by two large-scale fining upward trends: conglomerates are confined to the Permian and the supposed lowermost Triassic, (both of which were deposited in more or less restricted intermontane depressions) and pass up into mudstones ascribed to the Aylesbeare and Mercia Mudstone Groups respectively (Fig. 5).

The Permian, Exmouth and Dawlish Sands of the east Devon coast pass up into mudstones of the Aylesbeare Group which are in turn sharply overlain by Early Triassic Budleigh Salterton Pebble Beds (Fig. 5). The latter alternate with, and pass up into, sandstones ascribed to the Otter Sandstone Formation. Together the Budleigh Salterton Pebble Beds and the Otter Sandstone comprise the widespread and important Triassic Sherwood Sandstone Group (Fig. 5). The upper part of the sequence is formed by the extensive argillaceous Mercia Mudstone Group, known in the subsurface to include localised evaporites. The Penarth Group at the top of the Triassic succession heralds the effects of widespread Liassic marine transgression that led to the re-establishment of marine waters in the area for the first time since the Carboniferous.

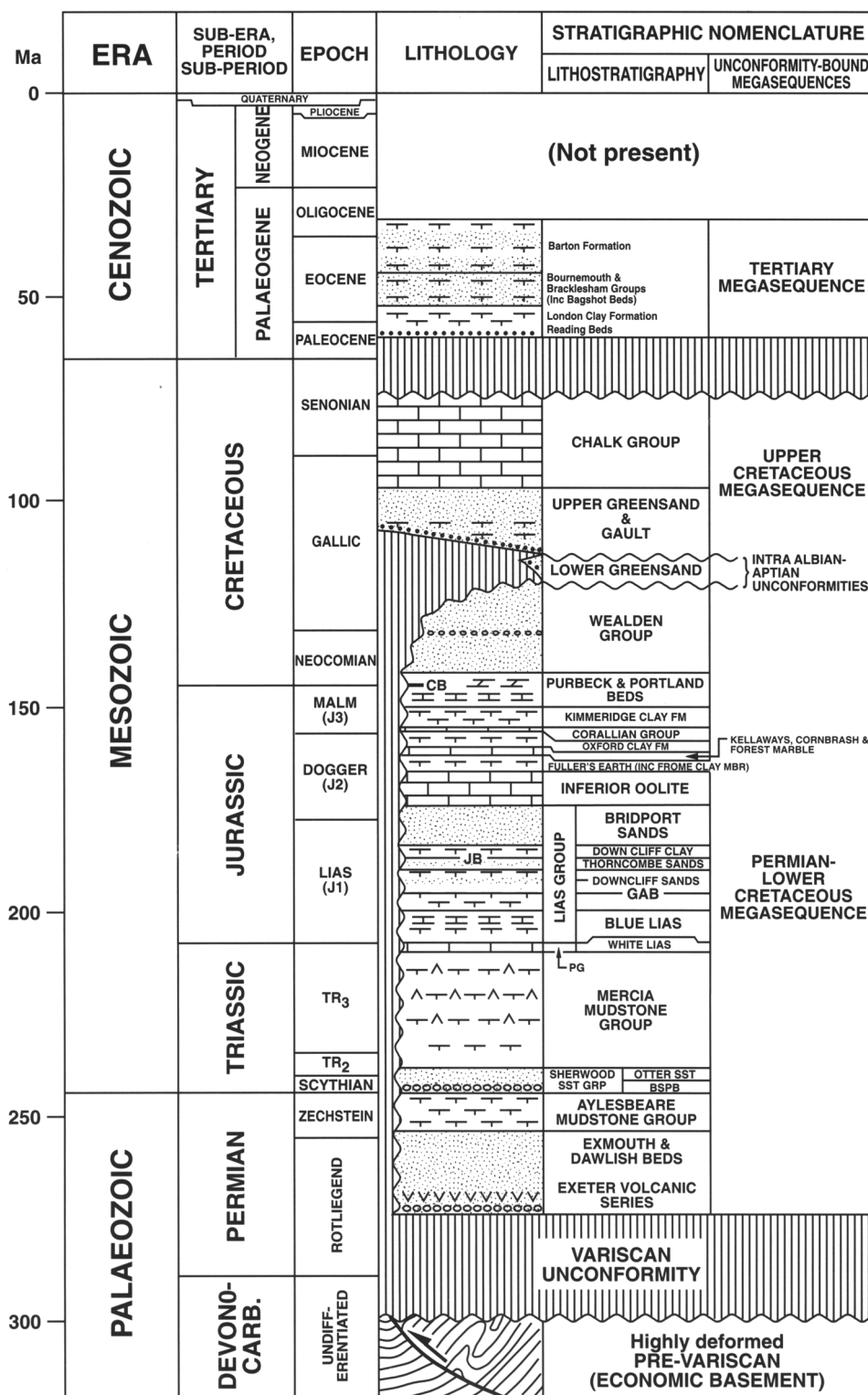


Fig. 5. Generalized stratigraphical column for the Wessex Basin illustrating the main megasequences and stratigraphic nomenclature currently used in the basin (JB, Junction Bed; CB, Cinder Bed; GAB, Green Ammonite Beds; PG, Penarth Group; BSPB, Budleigh Salterton Pebble Beds).

The middle division contains of the dominantly marine sediments of Jurassic age. It consists largely of a broadly cyclic repetition of shallow marine mudrocks, sandstones and limestones. Many formations have been defined and mapped but, with the exception of local facies variations, particularly in some of the carbonates, all appear to be remarkably widespread in the basin. The Jurassic contains all of the potential source rocks in the region, and one major reservoir (the Bridport Sands at the top of the Lower and base of the Middle Jurassic) and a number of minor potential reservoir formations including the Corallian Benclyffe Grit (Allen & Underhill 1989, 1990; Goldring *et al.* this volume), Frome Clay and Cornbrash. The top of the succession records a major marine regression and the highest of the limestones, the Portland Limestone, passes up into sabkha and brackish water sediments (the Purbeck), and thence into the entirely non-marine Lower Cretaceous Wealden Group.

The sediments of the Wealden Group have a distribution in Dorset apparently localised along the strike south of major syn-sedimentary faults. They are essentially of fluvial origin, although lacustrine environments are well represented in the considerably thicker succession in the Isle of Wight. Evidence exists for continued extensional movement on several of the E–W-trending faults during the Early Cretaceous. For example, Ruffell & Garden (1997) document contemporaneous tectonic control by the Isle of Wight Fault on sediment dispersal in the Lower Greensand Group.

Upper Cretaceous megasequence

The Upper Cretaceous megasequence is separated from the underlying Permian–Lower Cretaceous megasequence by an important Albian–Aptian unconformity, which is marked by the progressive westerly truncation of Mesozoic and Permian strata. The lowest part of the Upper Cretaceous megasequence consists of westerly-onlapping, diachronous, marine, and commonly glauconitic sandstones which pass up into the familiar Chalk which shows evidence of thinning in the far west.

Lateral variation in thickness and Chalk lithofacies, including the development of slumps, slip scars and local lacunae have all been recorded in the Wessex Basin (Gale 1980; Mortimore & Pomeroy 1997). Their close spatial association with areas that subsequently became axes of inversion suggests that the E–W-trending buried faults that either remained active in

extension or, more likely, began to show the effects of contractional reactivation during the late Cretaceous.

Tertiary megasequence

The Tertiary succession is separated from the underlying megasequence by an important, but subtle, regional disconformity. The stratigraphic break covers the Maastrichtian and most of the Paleocene. The overlying sediments that comprise the Tertiary megasequence consist of near-shore marine and non-marine sediments and are largely confined to the area east of Dorchester (Fig. 4c). The megasequence reaches a maximum thickness of over 600 m in the north of the Isle of Wight as proven by the Sandhills-1 borehole. Depositional facies analysis of Upper Eocene (Priabonian) sections demonstrates that the basin was dominated by lacustrine and brackish lagoonal environments which were recharged by marine waters through a restricted inlet in the east Solent area (Hamblin *et al.* 1992).

Development and evolution of structural styles

Cross section geometries

Surface outcrops highlight the importance of several important zones of disturbance affecting the Chalk (Arkell 1947; e.g. landsat image of Fig. 3). Integration of seismic data with borehole data and field observations enable the construction of representative structural cross-sections (e.g. Figs 6 & 7; Stoneley 1982). The sections not only demonstrate the occurrence of east-west trending extensional growth faults beneath the present zones of disturbance but also in other areas of the basin. The sections also serve to illustrate the role that many of these extensional faults had on depositional thicknesses and structural geometries during the Triassic, Jurassic and Early Cretaceous. Extension not only controlled structural geometries at a basin-scale but also appears to have been important at more local outcrop scales too (e.g. Hunsdale & Sanderson this volume).

Of the major E–W zones of Mesozoic extension, by far the most significant are the system of structures that comprise the intra-basinal Purbeck–Isle of Wight fault system. Variation in structural styles seen along the length of the individual, en-echelon fault segments that collectively form the Purbeck–Isle of Wight fault system may in part be due to the presence of

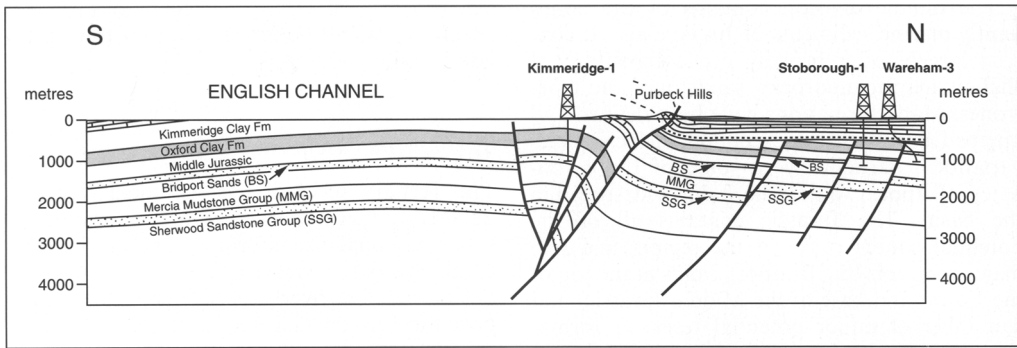


Fig. 6. North-south cross-section through Kimmeridge, Stoborough and Wareham illustrating the nature and extent of the structural inversion related folding in the hangingwall and Mesozoic extensional tilted fault blocks in the footwall of the Purbeck Fault.

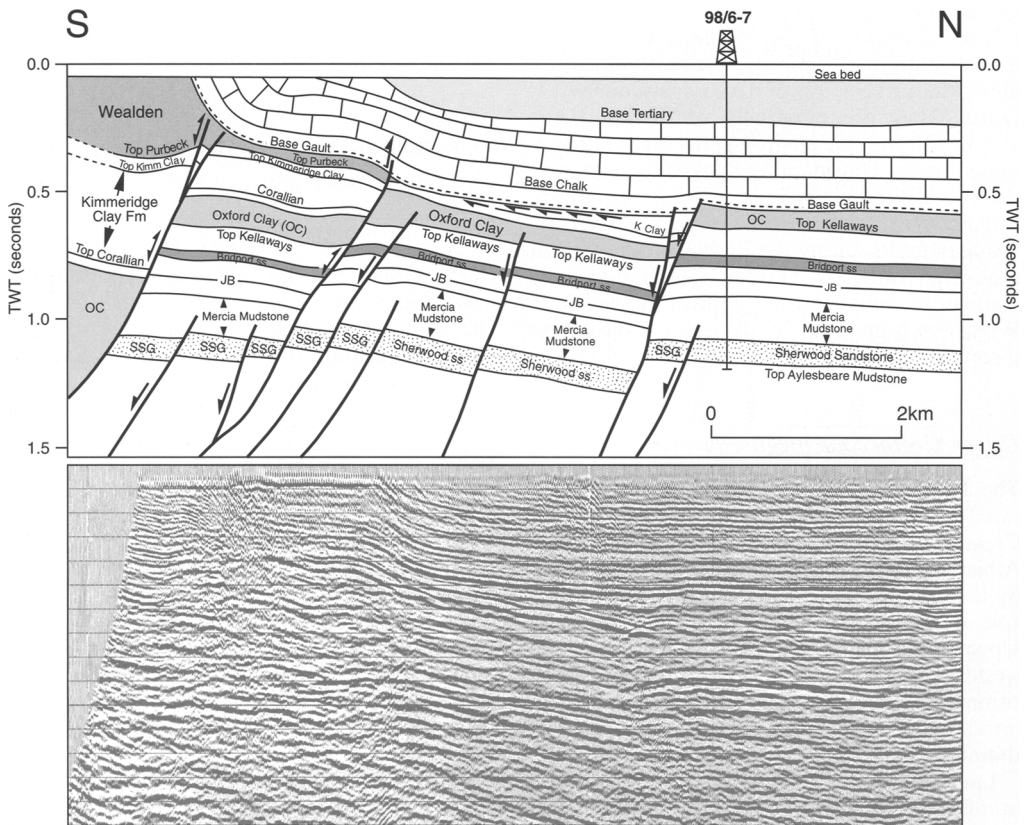


Fig. 7. North-south seismic line and interpreted cross-section through the offshore extension of the Wytch Farm oilfield. The presence of a second monoclinical fold at the base of the Late Cretaceous demonstrates that at least one tilted fault block was affected by the structural inversion process in addition to the more obvious presence of the major structural inversion-related hangingwall anticline. (OC, Oxford Clay; JB, Junction Bed; SSG, Sherwood Sandstone Group.)

easy slip (decoulement) horizons in the Triassic in western parts of the basin (Stewart *et al.* 1996; Harvey & Stewart this volume). Several workers believe that there is evidence that syn-sedimentary roll-over anticlines developed in the hanging walls to many of the extensional faults, particularly those that have a more listric geometry due to the presence of a salt decollement at depth (e.g. Selley & Stoneley 1987).

Extension on component fault systems of the Wessex Basin appears to have largely ceased during Early Cretaceous times, and except for those characterised by unusual Chalk lithofacies, most were essentially inactive during Late Cretaceous deposition which is generally considered to represent the period of post-rift sedimentation. Total displacement on parts of the Purbeck–Isle of Wight fault system are now known to have had a cumulative pre-Tertiary displacement in excess of 2 km.

Towards the end of the Cretaceous and early in the Tertiary, initiation or continuation of south to north compression led to pronounced reversal of movement and structural inversion on many of the formerly extensional Wessex Basin fault segments including those bounding the Central Channel High (Beeley & Norton this volume). Structural inversion along the

Purbeck–Isle of Wight fault system led to relative uplift of the Channel (Portland–Wight) Basin. The amount of uplift has been estimated to be approximately 1.5 km from outcrop geology which is consistent with estimates derived from sonic velocity data (Law this volume) and apatite fission track data (Bray *et al.* this volume). The inversion had the effect of modifying former extensional structures along the whole length of the basin (e.g. Butler this volume; Smith & Hatton this volume), with the creation of major northwards-verging monoclinal folds above the reactivated faults (e.g. the Purbeck–Isle of Wight Disturbance), modification of any pre-existing roll-over anticlines and the formation of periclinal folds in hangingwall locations and the initiation of local thrusting in the post-rift sediments (Underhill & Paterson 1998). Outwith the areas affected by Tertiary fault reactivation, the dips in the Upper Cretaceous are for the most part very gentle.

Strike-section geometries

In marked contrast to the N–S-trending dip sections, east–west (strike-parallel) cross-sections demonstrate a much simpler structural picture. There is little evidence of fault-controlled

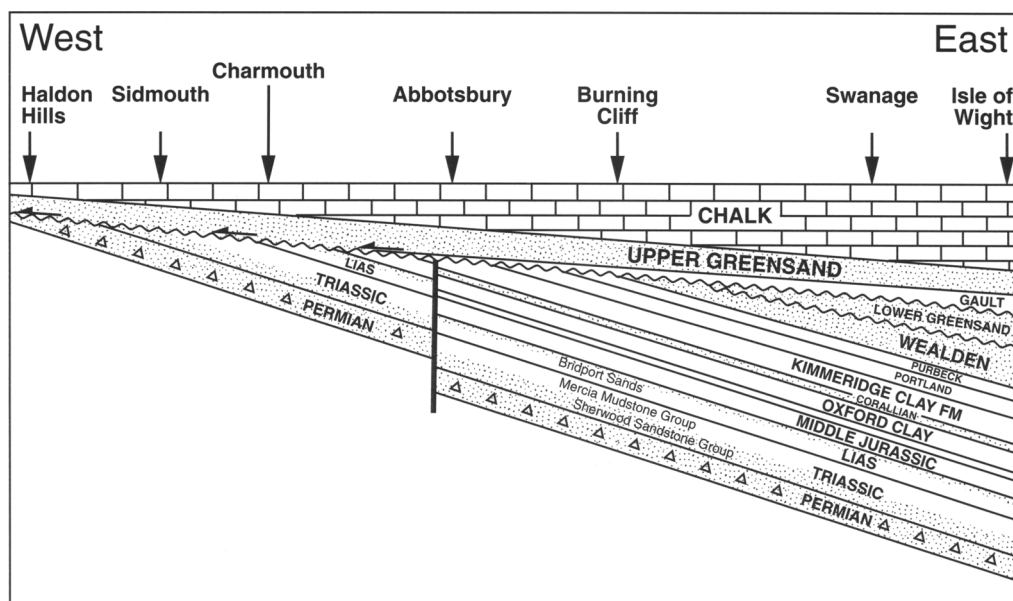


Fig. 8. Diagrammatic representation of the east–west effects of, and progressive westerly subcrop of, Jurassic–Permian strata beneath the intra-Cretaceous unconformity across the Wessex Basin. The occurrence of this particular unconformity is interpreted to have been detrimental to the area's hydrocarbon prospectivity since it probably inhibited source rock maturation in western areas as well as imparting a pronounced easterly tilt to previously formed extensional tilted fault blocks.

depositional thickness changes along strike during deposition of the Jurassic–Early Cretaceous. However, marked stratigraphic onlap and pinch-out of Permian and Triassic sedimentary units (including the Sherwood Sandstone Group; Fig. 3a) is recorded towards the basin margin (e.g. Butler this volume).

E–W-trending structural cross-sections do, however, demonstrate that an important easterly tilt was imparted to the basin during the Early Cretaceous (Fig. 8). The underlying Permian–Jurassic sequence was subjected to erosion and shows progressive truncation towards the west (e.g. McMahon & Underhill 1996; McMahon & Turner this volume), the derived sediment probably mostly passing eastwards into the Weald Basin. Subsequent westerly transgression during the Aptian and the Cenomanian eventually led to cover of the truncated Jurassic, Triassic and Permian above the megasequence bounding unconformity.

Hydrocarbon habitat

For any area to become a successful hydrocarbon province, a number of factors must be satisfied. There must be one or more suitable *reservoirs* capped by coherent *seals*. There must be a candidate *source rock* with sufficiently high total organic carbon content. Well-defined *trap* configurations must exist, be they obvious structural closures or more subtle stratigraphic features. Even given all the of the above, an area would remain unprospective without source rock *maturation* due to burial, the existence of suitable *migration routes* from source to trap and, most importantly, appropriate *timing* of reservoir-bearing trap formation relative to hydrocarbon migration. Finally, *preservation* of any accumulation must be maintained.

That the Wessex Basin contains producing oilfields attests to the fact that all the factors controlling hydrocarbon prospectivity have been met, at least locally. Integration of onshore outcrops with subsurface (seismic and borehole) data enables consideration of each of the essential requirements which have combined to make selected parts of the Wessex Basin highly prospective. Each of these essential requirements will now be reviewed in turn.

Reservoirs

Potential reservoirs are present in many parts of the succession, some of major and some of apparently more minor significance. Review of onshore exposures suggests that the basin's

main reservoir potential is provided by siliciclastic units. However, some minor carbonate reservoirs also exist.

In the lower part of the outcropping sequence, the best potential would be provided by the Permian aeolian sands of East Devon. They have surface porosity up to 40% and are possibly equivalent to the Rotliegend sandstones of the Southern North Sea. The Permian sandstones, however, are not generally considered to have a high reservoir potential because it is believed that they either do not extend sufficiently far to the east in the subsurface or lie below structural closure to be of significance in the basin.

Sandstones are frequent in the Lower Triassic succession. They reach their optimum development in the Triassic Sherwood Sandstone Group. The formation is extensively exposed between Budleigh Salterton, Otterton and Sidmouth, where its thickness approaches 120 m (Lorsong & Atkinson 1995). The unit comprises an almost continuous, high net:gross arkosic sandstone body with limited mudstone lenses. Facies analysis suggests that the Sherwood Sandstone Group consists of braided alluvial deposits and perennial sheetflood sandstones, with the local development of distributary channels and a couple of aeolian sandstones interbedded with subsidiary playa lake and floodplain mudstone lenses (e.g. McKie *et al.* this volume and references therein). The latter occasionally contain palaeosols (e.g. Purvis & Wright 1991; Wright *et al.* 1991). At Wytch Farm, the Sherwood Sandstone Group is interpreted to have been deposited in a mixed fluvial and lacustrine proximal braided alluvial plain setting (Dranfield *et al.* 1987; Bowman *et al.* 1993; McKie *et al.* this volume). Significantly, the Sherwood Sandstone Group forms the main reservoir unit (*c.* 150 m thick) in the Wytch Farm Field (McKie *et al.* this volume), where it is generally similar to the outcrops, even though the facies associations appear not to be continuous in the subsurface in between. Porosities up to nearly 30% have been measured with permeabilities in the darcy range.

The stratigraphically lowest potential reservoir in the Lower Jurassic interval is the Thorncombe Sands which lie towards the top of the Lias Group and are exposed at Watton Cliff near Bridport. Since they are relatively thin (23 m) and very fine-grained sandstones with porosity only in the range 7–10% and permeability of approximately 25–30 mD, the Thorncombe Sands have not excited as much interest as either the underlying Sherwood Sandstone Group or the overlying, Bridport Sandstone. However, they are believed to contain oil in the vicinity of Wytch Farm.

Of more significance are the diachronous 41 m thick Bridport Sands which lie at the top of the Lias Group and extend up into the Aalenian. The sands are fairly uniformly very fine to fine-grained, clean with outcrop porosities up to 15% and permeability up to 250 mD (and up to 32% and 800 mD at Wyth Farm). They are interrupted by numerous 0.33 m thick cemented beds which could be barriers to cross-formational fluid flow. The sands are believed to be shallow marine, whilst the origin of the cemented layers is still debatable (Bryant *et al.* 1988). They are capped by a thin (3 m) limestone representative of the Inferior Oolite which, where fractured, has yielded oil in the vicinity of Wareham. The Bridport Sands (*c.* 70 m thick) form the upper reservoir in the Wyth Farm Field (Colter & Harvard 1981).

Thin limestones in the Middle Jurassic, the Forest Marble and the Cornbrash, are similar to the Inferior Oolite in that they too have little natural porosity. However, the Frome Clay Member does contain oil at Wyth Farm and the Cornbrash has been proven to act as a minor reservoir in the Kimmeridge oilfield where it has been extensively fractured (Evans *et al.* this volume).

In the Upper Jurassic, exposures of the mixed siliciclastic-carbonate sequence of the Corallian Group suggest that it could offer some reservoir potential in the subsurface, particularly the approximately 3 m thick fine-grained sandstones known as the Benclyffe Grit. Interestingly, at outcrop at Osmington Mills, the sandstones show signs of having been extensively impregnated with oil and still provide a live seepage (Allen & Underhill 1989). Despite this, however, there are no known occurrences of Corallian oil-bearing reservoirs in the subsurface to date.

The Portland Limestone at the top of the Jurassic is porous in two facies: there is still some primary porosity in oolitic grainstones and secondary dissolution occurs in bioclastic packstones. It could conceivably provide a target beneath the Upper Cretaceous unconformity to the north of the Purbeck-Isle of Wight Disturbance if it could be located seismically, although the carbonate develops a more chalky facies inland from the coast.

Restricted fluvial sands in the continental Wealden Group might conceivably provide minor reservoirs, but it is unlikely that they are sealed in the subsurface in southern Dorset. The Upper Cretaceous and Tertiary do not have any significant reservoir potential in Dorset since carbonates of the Chalk Group usually lack porosity and effective permeability and the Tertiary clastics occur at or near surface.

Seals

All of the major potential reservoir sandstones are each covered by a substantial thickness of mud rocks which have good sealing potential. The Permian sandstones are overlain by mudstones of the Aylesbeare Group. The Sherwood Sandstone Group is overlain by the red silty mudstones and local evaporites of the Upper Triassic Mercia Mudstone Group, which is over 350 m thick near Sidmouth. The Bridport Sands and Inferior Oolite are overlain by 190 m of the bentonitic clays of the Bathonian Fuller's Earth.

Source rocks

Potential source rocks are confined to the Jurassic and occur at three main levels. In the vicinity of Lyme Regis and Charmouth, and also in the subsurface to the east, black shales of the Lower Lias reach some 100 m in thickness (House 1993). In the lower part of the section they alternate with pale, very fine-grained limestones approximately 30–40 cm thick. Although marginally immature at outcrop, a total organic carbon content (TOC) of up to some 8% has been measured (Ebukanson & Kinghorn 1985); the organic matter is predominantly Type II algal material.

Potential source rock horizons also occur in the Middle and Upper Jurassic. Some source rock potential has been proven to occur in the lower part (Upper Callovian) of the Oxford Clay, on the shore of the Fleet Lagoon and in abandoned brickpits in the neighbourhood of Chickerell some 7 km WNW of Weymouth, as well as in the subsurface to the east.

The Kimmeridge Clay in the Upper Jurassic reaches a combined total of some 520 m in outcrops at Burning Cliff and at Kimmeridge Bay itself. The succession consists of interbedded black anoxic shales and fine dolomitic limestones. TOCs up to about 20% have been measured (Farrimond *et al.* 1984), although some 70% has been recorded from the 1 m thick Kimmeridge Oil Shale just above the middle of the section. Like the Liassic source rock intervals, Type II organic matter is marginally immature at outcrop (vitritinite reflectance equivalent 0.48%; Ebukanson & Kinghorn 1985).

Traps

Two main possible trap types predominate in the Wessex Basin: periclinal closures mainly related to structural inversion and buried, tilted extensional fault-blocks. To date, no evidence

exists for the presence of any stratigraphic plays. The periclinal closures are seen running parallel to, on the south side of, and up to 2 km from the Purbeck–Isle of Wight line of inversion (e.g. Kimmeridge). These are limited in length and largely correspond to the centres of individual fault segments. Whilst the southerly and along plunge dips are very gentle, the north flanks of the periclinal commonly steepen into the main fault. Although these periclinal were clearly uplifted and no doubt modified, possibly even breached, by the Tertiary structural inversion and uplift, it has been argued that some may have developed as hanging wall roll-overs during extension at least in the late Jurassic–early Cretaceous (Stoneley 1982). However, most smaller anticlines close to the disturbance to the west are now believed to have formed largely during Tertiary inversion (including the Poxwell Anticline; Mottram & House 1956).

Although early exploration was directed towards the periclinal traps (Buchanan this volume), the advent of seismic data led to the initial recognition and ultimate successful test for hydrocarbons in buried tilted extensional fault blocks lying to the north of the Purbeck–Isle of Wight fault system in the Wareham area. It is the occurrence of these tilted fault blocks adjacent to the active kitchen area to the south that provides the main structural plays to the basin including the Wytch Farm and Wareham oilfields (Fig. 8; Colter & Harvard 1981). A series of such tilted fault-blocks and terraces have been defined in the basin. In almost all cases, faults defining the blocks north of the Purbeck–Isle of Wight Disturbance remain in net extension and appear to have been little affected by the structural inversion process other than possibly by converting former channels of migration into seals.

Maturity

At outcrop, all of the potential source rocks are immature for oil generation. However, there is ample evidence for source rock maturation having occurred prior to tectonic inversion in the Tertiary. Basin modelling supported by well data suggest that the Lower Lias has reached peak oil generation throughout the area to the south of the Abbotsbury–Purbeck–Isle of Wight disturbance and that, in the east, the Oxford Clay just entered the oil window (e.g. Penn *et al.* 1987, fig. 4). To the east of Swanage, the Lower Lias has been buried deeply enough to raise the possibility of significant gas generation.

The expectation that maturation has occurred is supported not only by the presence of producing oilfields but also the occurrence and distribution of seepages. There are a number of biodegraded oil seeps and impregnations in Jurassic and Wealden beds along the coast between Osmington Mills and Worbarrow Bay east of Lulworth Cove (Bigge & Farrimond this volume), and gas seepages have been reported from the sea-floor south of Swanage (Stoneley 1992).

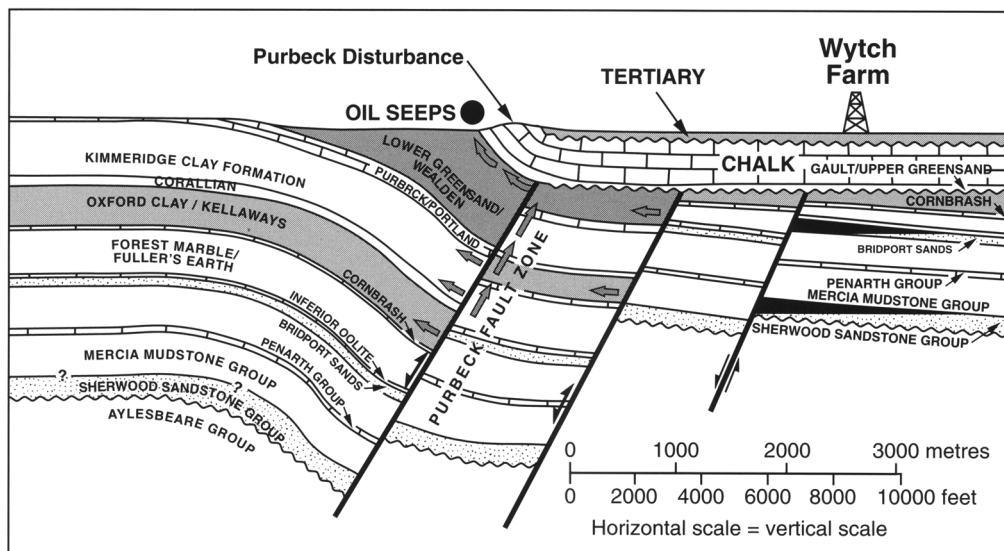
The oil seep in the Wealden at Mupe Bay has proved to be a particular focus of research, and its genesis and evolution have been subject to considerable debate (e.g. Selley & Stoneley 1987; Hesselbo & Allen 1991; Miles *et al.* 1993, 1994; Kinghorn *et al.* 1994; Wimbledon *et al.* 1996; Bigge & Farrimond this volume; Parfitt & Farrimond this volume; Hesselbo this volume). A channel sandstone contains boulders of mineralogically similar sandstones bound together by black residual oil. These have been taken by some to be evidence for the existence of eroded and reworked sediment impregnated by a nearby Early Cretaceous palaeo-oil seepage (Selley & Stoneley 1987; Kinghorn *et al.* 1994; Wimbledon *et al.* 1996). As the channel sandstone also contains a live, light oil, it has been argued that the outcrop marks the site not only Early Cretaceous but also of recent seepage. Irrespective of its exact evolution, however, the Mupe Bay exposures together with the other known seeps have been successfully typed to a Lower Lias source (Cornford *et al.* 1988).

Migration

Given the likelihood that the proven Lower Lias source rock only reached maturity in the kitchen area south of the Purbeck–Isle of Wight disturbance, charge into the South Dorset Shelf was reliant upon leakage across the Purbeck–Isle of Wight fault system and upwards migration to backfill tilted reservoirs in the footwall to the extensional fault segments (Fig. 9). Such a mechanism is envisaged for the filling history both of the Sherwood Sandstone Group and Bridport Sands together with other minor reservoirs, within the tilted fault blocks located to the north of the kitchen area. Support for such a mechanism comes from the occurrence of the numerous oil seeps in locations where they could be fed by migration up the plane of faults. BP's Kimmeridge oilfield may be an important exception to this rule, but it remains the only producing oilfield in the hangingwall to the reactivated Purbeck fault (Fig. 6; Evans *et al.* this volume).

South

North



South

North

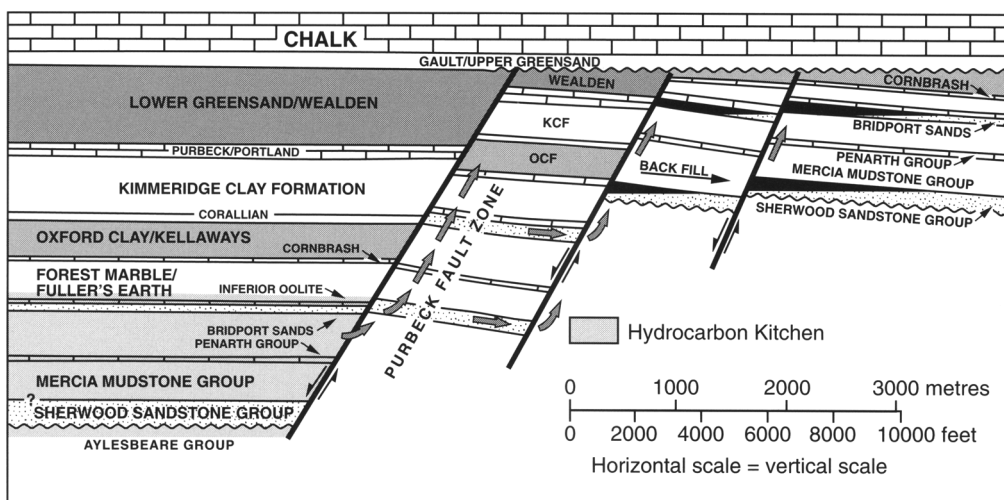


Fig. 9. North-south present-day and Late Cretaceous (restored) cross-sections through Wytch Farm depicting the main controls on hydrocarbon maturation and migration in the area. Modified after Colter & Harvard (1981). (KCF, Kimmeridge Clay Fm; OCF, Oxford Clay Fm.)

Timing of generation, migration and entrapment

Generation of hydrocarbons from the Channel (Portland–Wight) kitchen area occurred prior to Tertiary inversion. Analysis of burial histories for wells located in the Channel (Portland–Wight) depocentre, and the supposed fossil seepage at Mupe Bay, suggest that the Lower Lias entered the oil window by Early Cretaceous times with peak generation in the Middle to Late Cretaceous (Fig. 9). Whilst source rock maturation is likely to have been inhibited or stopped in western areas affected by Albion–Aptian tilting (i.e. west of Lulworth), the main Channel (Portland–Wight) kitchen probably continued to generate hydrocarbons. That kitchen area was probably only switched off when uplift south of the Purbeck–Isle of Wight fault system commenced some time between the Campanian and the Late Palaeocene (Fig. 9).

The disposition of known accumulations requires that the faults that acted as channels of migration were sealed over by the Upper Cretaceous at the time of maximum migration to prevent escape to surface, and that they subsequently became sealing probably due to the onset of compression (e.g. Selley & Stoneley 1987). As in many sedimentary basins affected by tectonic inversion, structures like the periclinal folds that formed during the tectonic inversion process (e.g. Poxwell) would have been reliant upon late-stage remigration for them to be successful plays. As the relative disappointment of exploratory well results sited on such periclinal folds suggests that such re-migration was of relatively minor importance in the Wessex Basin.

Finally, understanding of the structural inversion history, superimposed on a very gentle overall eastwards plunge towards the centre of the sub-basin, is critical to the interpretation of the petroleum geology because it implies that long-established unbreached palaeostructures are likely to be restricted to the eastern parts of the basin lying north of the principal axes of inversion.

Preservation of accumulation

Once an accumulation is in place, it must be preserved intact and not permitted to escape. Although many remain undeformed, some palaeostructures that existed at the end of the Cretaceous appear to have been affected by the structural inversion process and either partially or totally reconfigured by the effects of fault reactivation and basin inversion during the Tertiary. Indeed, whilst Tertiary deformation

appears to have been particularly severe in the immediate vicinity of the Purbeck–Wight Disturbance, large areas to the north seem to have remained largely unaffected (e.g. the fault block containing the Wytch Farm oilfield) suggesting that the footwall to the Purbeck–Wight fault system acted as a rigid buttress with most of the compressional strain taken up on it or within the Channel Basin (Underhill & Paterson 1998). Intense fracturing in the Chalk, exposed along the Purbeck–Isle of Wight Disturbance (e.g. at Lulworth Cove) might have created a seal risk for the fault block immediately to the north, which has indeed been found to be water-bearing although with residual oil staining. More than a few hundred yards away to the north, however, where the Chalk remains undeformed, hydrocarbon accumulations have remained unbreached as is evident at Wareham and Wytch Farm.

Limits to the hydrocarbon play fairway

Assessment of the above factors leads to the conclusion that there may be effective limits to the main hydrocarbon play fairway. The interpreted limits to the main Sherwood Sandstone Group and Bridport Sands plays are governed by the respective pinch-out of the lower, and shale-out of the upper reservoir interval towards the east, the line to the west of which either the source rock never reached maturity or was affected by intra-Cretaceous uplift, and to the south by the faults and the tilted fault blocks that they define that show the effects of contractional reactivation. The resultant play fairway thus appears to be limited to the area covered by the Isle of Purbeck (north of the Purbeck Disturbance), Poole Harbour and Bournemouth Bay, but appears not to extend to Solent or to northern areas of the Isle of Wight. The northerly limit to the play fairway, however, is not well defined but is probably controlled by the distance that oil could migrate from the kitchen area and hence, is dependant upon the availability of migration routes. Although the presence of oil at Stockbridge (Fig. 2) might, however, be taken as evidence that some oil was able to migrate long distances to the north of the Channel (Portland–Wight) depocentre, or from the more local Pewsey basin, it is more likely that the field is sourced from the Weald Basin (Butler & Pullan 1990).

Oil production and the Wytch Farm oilfield

Despite the profound bias resultant from oil production rates from one field, Wytch Farm,

volumetrically oil production from the Wessex basin has now overtaken that from the East Midlands and Weald Basin, thus making it Britain's most prolific hydrocarbon area.

To date three producing fields have been discovered in the Wessex Basin: Wyth Farm, Wareham and Kimmeridge. The first two of these occur within the Sherwood Sandstone play fairway defined above. It is worth noting that although often shown as a separate accumulation, the Arne discovery is now considered to form an integral part of the Wyth Farm oilfield. Furthermore, the offshore 98/7-2 discovery may also represent an easterly extension of the field rather than a separate accumulation since it has the same oil–water contact.

Of the discoveries to date, however, by far the most significant is the Wyth Farm oilfield which is the largest onshore field in western Europe. Although the field was discovered when the oil-bearing Bridport Sands were penetrated in 1974, its full potential was not realised until 1977 when an appraisal well was deepened to test for possible hydrocarbons in the Sherwood Sandstone Group (Fig. 7; Colter & Harvard 1981; Buchanan this volume).

Volumetrically the Wyth Farm oilfield largely comprises two main reservoir units: an upper, Bridport Sands reservoir and a lower Sherwood Sandstone Group reservoir. A minor contribution also comes from the Middle Jurassic Frome Clay Member. The field is now thought to have had a stock tank oil initially in place (STOIIP) of 924 MMbbls and contain oil reserves slightly in excess of 428 MMbbls of which just under one-half remain to be produced (239 MMbbls have been produced up until 31/12/97). The main Sherwood Sandstone Group reservoir had a STOIIP estimate of 754 MMbbls of which 397 MMbbls were thought to be recoverable (52% recovery efficiency). The Bridport Sandstone is believed to have contained a STOIIP of 120 MMbbls of which 27 MMbbls (23%) is thought to be recoverable, and the Frome Clay Member had an estimated STOIIP of 50 MMbbls and approximate reserves of 4 MMbbls (8% recovery efficiency).

STOIIP and reserve estimates for Wyth Farm dwarf those of the other two producing fields and other discoveries in the area. Current estimates suggest that the Wareham field had a STOIIP of 21 MMbbls of which 5 MMbbls are thought to be recoverable. Kimmeridge has a STOIIP of 10 MMbbls, reserves of 3.2 MMbbls of which 3 MMbbls have been produced to date. The 98/7-2 discovery is believed to contain an additional 20 MMbbls in reserves which are

currently not included with the Wyth Farm statistics.

Development of Wyth Farm, which initially took place in the 1980's, has more recently been extended to include that part of the structure that runs offshore beneath Poole Harbour and Bournemouth Bay (see McClure *et al.* 1995, fig. 2). Innovative drilling technology including the use of highly deviated extended reach wells has been used to drain the field (McClure *et al.* 1995; Hogg *et al.* 1996; McKie *et al.* this volume) whilst at the same time avoiding the need to put rigs or other infrastructure in such an environmentally sensitive area.

Conclusions

(1) The Wessex Basin and the successor Hampshire Basin contain a Permian–Oligocene sedimentary fill which may be subdivided into three unconformity-bound megasequences, each of which record important phases in the development and evolution of the basin.

(2) The lower, Permian–Lower Cretaceous megasequence records several phases of extensional faulting which led to the creation of numerous intra-basinal depocentres, tilted fault-blocks and terraces. It also contains at least two main sealed reservoir intervals in the Sherwood Sandstone Group and the Bridport Sands and at least three potential source rock intervals in the Lias Group, the Oxford Clay and Kimmeridge Clay Formation.

(3) Burial of the Liassic source intervals in areas south of the Purbeck–Wight intra-basinal segmented, extensional fault system led to maturation and migration of hydrocarbons from Early Cretaceous times. Whilst hydrocarbon generation was probably arrested in western areas that experienced intra-Cretaceous (Albian–Aptian) uplift, maturation and migration continued in eastern areas until Late Cretaceous times. Neither the Kimmeridge Clay nor Oxford Clay formations appear to have been matured for hydrocarbon generation anywhere in the basin at any time.

(4) Late Cretaceous and Tertiary compression led to contractional reactivation and structural inversion along the line of many of the former extensional structures (e.g. Purbeck–Isle of Wight fault system), uplift of the Channel (Portland–Wight) sub-basin and formation of north-facing monoclines and numerous periclinal folds.

(5) An understanding of the tectono-stratigraphic development and evolution of the Wessex Basin helps determine why the basin's

hydrocarbon prospectivity appears to be concentrated in the east Purbeck, Poole Harbour and Bournemouth Bay areas. It is only there that the extensional palaeostructures containing Sherwood Sandstone Group and Bridport Sands reservoirs have been unaffected by the pronounced effects either Albian–Aptian easterly tilting or by Tertiary tectonic inversion.

(6) As in other structurally inverted sedimentary basins in which the kitchen area has been switched off, hydrocarbon charge into subsequent, inversion-related periclinal folds relies upon remigration from breached palaeostructures. Despite numerous exploratory wells, it appears that re-migration did not play a major role in the basin. Nevertheless, some periclines modified during the structural inversion episode may, as at Kimmeridge, have retained from Cretaceous times or received oil by limited remigration.

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